Staff Summary
ARB LCFS Pathway for the
Production of Biomethane from the
Mesophilic Anaerobic Digestion of Wastewater Sludge at a
Publicly Owned Treatment Works (POTW)

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Pathway Summary

Staff has developed two Low Carbon Fuel Standard (LCFS) pathways for the production of biomethane from the mesophilic anaerobic digestion of wastewater sludge at a wastewater treatment plant (WWTP) located at a publicly owned treatment works (POTW). The biomethane produced would be used as transportation fuel and could be dispensed on-site through a compressed gas vehicle fueling station, or may be injected into the natural gas pipeline system ("common carrier pipeline") for dispensing at an off-site compressed gas vehicle fueling station.

Wastewater sludge is generated from the primary and secondary treatment processes designed for the municipal wastewater that flows into the WWTP. Since the wastewater sludge content is primarily organic material, California State and local laws require further treatment of the wastewater sludge prior to discharge of the material as an effluent, or disposal in a landfill or in a land application site. One of the most common processes for the treatment of wastewater sludge at a POTW is the anaerobic digestion of the sludge under mesophilic operating conditions (35 degrees Celsius). Anaerobically digesting the wastewater sludge destroys part of the organic matter and produces biogas, a mixture comprised of methane (CH_4) and carbon dioxide (CO_2), along with some trace impurities such as hydrogen sulfide, siloxanes, and vinyl chloride. Since both major components of biogas are greenhouse gases (GHG), the biogas produced is further destroyed by flaring (methane capture and destruction), or used in a device that generates electricity from the combustion of the biogas.

An alternative fate for the biogas, which is comprised of approximately 58 percent methane by volume, is to further refine the biogas to remove the carbon dioxide and other trace impurities to produce near-pure biomethane (greater than 99 percent CH_4). This biomethane could then be compressed and sold as a vehicle fuel either on-site, or injected into the common carrier pipeline for fueling at an off-site location. Some POTWs may continue to use part of the biogas or biomethane in compliant energy-producing devices for the production of renewable power and only allocate a fraction of their biogas produced toward transportation fuel uses. These alternate fates for the biogas produced from the mesophilic anaerobic digestion of the wastewater sludge at a POTW are the basis of the LCFS fuel pathways below.

In order to estimate the GHG impacts of these pathways, staff utilized two versions of the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation life cycle analysis models: CA-GREET version 1.8b and GREET1 (2012).[1] For wastewater sludge treatment processes that include anaerobic digestion, digestate and supernatant management, biogas cleaning, refining, compression, dispensing and distribution, staff found that worksheets available in the GREET1 Model accurately estimated known energy use and material flow rates; therefore the GREET1 Model was used as a basis to estimate the energy use for the pathways, and CA-GREETv1.8b was used to estimate the GHG emission.

Based on a survey conducted by the California Association of Sanitation Agencies[2] of wastewater sludge management practices at over 250 POTWs in California, staff determined that approximately three-fifths of the POTWs operate anaerobic digesters to destroy part of the organic component of wastewater sludge. Of those found to be digesting wastewater organics, the majority of them (more than 90 percent) were found to be operating at mesophilic temperatures. Approximately 90 percent of those facilities digesting wastewater sludge were also using the produced biogas to provide renewable power for plant consumption or for export to the public grid, or both, and half of those POTWs producing power were doing so by use of internal combustion engines (ICE) and generators. The ICEs have come under increasing regulatory scrutiny due to more stringent emissions standards for stationary sources in local air districts.
The production of a transportation fuel, however, presents a viable solution to the regulatory constraints facing the POTWs.

Staff has estimated the CIs for biomethane produced under two alternative scenarios. The first is an estimate for biomethane produced at a Small-to-Medium POTW (Alternative Case 1) with wastewater inflows of 5-20 million gallons per day (MGD). In this model, only a small parasitic load on the biogas produced is used to heat the digesters. Grid-based electricity, using the California marginal mix of electrical generating assets, is assumed to power the wastewater sludge treatment, and biogas cleaning, compression, and fuel dispensing processes. The second is an estimate for a Medium-to-Large POTW (Alternative Case 2) with wastewater inflows of 21-100 MGD. In this model, the majority of the biogas is allocated to the production of renewable power using a compliant device (such as a gas-fired micro-turbine or turbine with an exhaust heat recovery system). The balance of the biogas produced in the digesters is allocated to on-site vehicle fueling, or compression and distribution through the natural gas grid for purposes of off-site vehicle fueling. Heat recovered from the exhaust of the combustion gases produced by the compliant device is adequate to sustain the mesophilic thermal requirements of the anaerobic digesters. The electrical demand for the wastewater sludge treatment and biogas cleaning, compression, and dispensing

[1] The CA-GREET model (Version 1.80b, December 2009) and the GREET1 Model (Revision 2, December 2012) were developed by Argonne National Laboratory (ANL). The CA-GREET model has been adapted for use in California (Life Cycle Associates and ARB Staff). Some emission factors listed in GREET1 and not available in CA-GREET were incorporated by reference.

[2] California Association of Sanitation Agencies, 2013. Survey of Publicly-Owned Treatment Work (POTW) Facilities in the State of California, February 2013.

processes is provided by the renewable power generated on-site by the compliant device. This alternative scenario also predicts that surplus cogenerated electrical power[3] will be produced, and that this power will be exported, displacing California marginal electricity on the electrical grid. Therefore, this model accrues an additional LCFS credit equal to the GHG emissions differential between the electricity generated on-site, and the California marginal grid-based electricity.

Common to both models is a credit for avoided flaring emissions. Staff assumes that due to regulatory and air quality non-attainment considerations, flaring of the biogas to achieve near complete destruction of the volatile components in the biogas with high global warming potentials is the only available option for the reference case. Therefore, any productive use of the biogas, such as for vehicle fuel or for the production of renewable electrical power, avoids the emissions and energy loss caused by flaring of the biogas. The avoided flaring emissions accrue as an LCFS credit in the pathway CI analyses.

The modeled CI results, along with the applicable avoided flaring emissions credit, and the credit for displaced grid-based electrical generation are presented in Table 1 below. The CI estimate for each alternative case presented is obtained by first estimating the total well-to-tank (WTT) GHG impacts, which arise from anaerobic digestion, digestate management and transport, biogas conditioning and refining, renewable power production, and biomethane compression, distribution, and dispensing. To this estimate is added the tank-to-wheels (TTW) GHG impacts, which arise when the finished fuel is combusted in a vehicle to derive motive power. This results in the total well-to-wheels (WTW) GHG emissions impacts, which, when expressed per unit of transportation fuel energy produced, represents the CI of the fuel.

As shown in Table 1, the resulting CIs are 30.51 g CO_2e/MJ and 7.89 g CO_2e/MJ for the two alternative scenarios presented. In both cases, staff estimated the CI for compressing biomethane for on-site with high-speed vehicle fueling. The CIs are also applicable to biomethane produced for injection into the common carrier pipeline.[4]

[3] The GREET1 Model estimates that electrical power surplus to the system boundary defined for the life cycle analysis of the scenario (Alternative Case 2) will be available for export. This amount of power is then considered to displace grid-based electrical generation.

[4] In most cases, the compression pressure required for pipeline injection (600-800 psig) is lower than the compression pressure required for high-speed vehicle fueling (3,600 psig).

Table 1: Summary of Life Cycle GHG Impacts and CIs for Biomethane Derived from Anaerobic Digestion of Wastewater Sludge

Parameter	Small-to-Medium POTW (Alternative Case 1)	Medium-to-Large POTW (Alternative Case 2)
Total WTT GHG Emissions Impacts (g CO_2e/day)	2,933,446.73	(8,799,057.62)
Total TTW GHG Emissions Impacts (g CO_2e/day)	4,646,249.17	18,601,504.67
Total WTW GHG Emissions Impacts (WTT + TTW) (g CO_2e/day) **(A)**	**7,579,695.90**	**9,802,447.05**
Digester Biomethane Yield (m^3/day)	6,931.35	34,656.77
Digester Biomethane Yield Fueling (scf/day)	133,366.58	1,223,754.81
Net Biomethane Available for Vehicle Fueling (scf/day)	79,893.36	319,857.30
Biomethane LHV (Btu/scf)	962.00	962.00
Biomethane Energy Value (MJ/day) **(B)**	**248,414.33**	**1,242,071.63**
Proposed Biomethane CI (g CO_2e/MJ) (A/B)	**30.51**	**7.89**

The proposed Lookup Table entries for the wastewater sludge-to-biomethane pathways are presented in Table 2 below:

Table 2: Proposed Lookup Table Entry for Fuel/Feedstock

Fuel	Pathway Identifier	Pathway Description	Carbon Intensity Value ($g\ CO_2e/MJ$)		
			Direct Emissions	Land Use or Other Indirect Emissions	Total Emissions
Compressed Natural Gas	CNG020	Biomethane produced from the mesophillic anaerobic digestion of wastewater sludge at a California publicly owned treatment works; on-site, high speed vehicle fueling or injection of fuel into a pipeline for off-site fueling; export to the grid of surplus cogenerated electricity.	7.89	0.00	7.89
Compressed Natural Gas	CNG021	Biomethane produced from the mesophillic anaerobic digestion of wastewater sludge at a California publicly owned treatment works; on-site, high speed vehicle fueling or injection of fuel into a pipeline for off-site fueling.	30.51	0.00	30.51

Applicable Operating Conditions

Use of these pathways by California publicly owned treatment works will be subject to the following operating conditions designed to ensure that the CI of the of the biomethane produced will remain at or below the values appearing in table above.

1. Every unit of biomethane reported under CNG020 and CNG021 must be produced from the low-solids anaerobic digestion (wet fermentation) of wastewater sludge generated at a California publicly owned wastewater treatment works (POTW). Digestion must occur under mesophillic conditions.

2. Every unit of biomethane reported under CNG020 must have been produced in a closed system consisting of the mesophillic anaerobic digesters that produce the CNG020 biomethane, and a compliant, combustion-powered electrical energy generation device. The electrical energy generation device

must provide the digesters with all the electrical and thermal energy they require. The thermal energy provided must consist of heat recovered from the device's exhaust gases. All of the fuel consumed by the generation device must consist of biogas from the digesters.

3. Every unit of biomethane reported under CNG021 must have been produced in a digester in which mesophillic conditions are maintained using heat produced from a portion of the biogas produced by the digester. The use of a portion of the produced gas to provide process thermal energy is referred to as a "parasitic thermal load." The electrical energy consumed by the digester must have been produced using the California marginal electrical energy generation mix.

4. Every unit of biomethane reported under CNG020 and CNG021 must have been dispensed to motor vehicles in one of two ways:

   a. Injection into the common-carrier pipeline system for off-site refueling, or
   b. Delivered on-site through a high-speed vehicle fueling station.

Staff Analysis and Recommendations

Staff has developed two LCFS fuel pathways for biomethane derived from wastewater sludge digested under mesophillic conditions at California POTWs. The pathway CIs were calculated using the CA-GREET v1.8b model. Material and energy balances extracted from GREET1 (2012) model were used as inputs to the CA-GREET model. Both pathways include a credit for the avoided flaring of the biogas from the digesters. CNG020, which applies to medium-to-large POTWs, includes a LCFS credit for the export of cogenerated electricity to the public grid. CNG021, which applies to small-to-medium POTWs, is a pathway dependent upon California marginal grid-based electricity or equivalent. Both pathways were posted for public comment and subsequently revised in light of the comments received. Staff is confident that these pathways accurately reflect sludge management operations at most small-to-medium and medium-to-large POTWs, and that they can be used by qualifying POTWs that produce biomethane for use as transportation fuel. For these reasons, staff recommends that these pathways be certified for use under the LCFS.